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RATIONAL MANAGEMENT OF CREATIVITY.

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RATIONAL MANAGEMENT
OF
CREATIVITY

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PREFACE

My choice of subject matter for this thesis was prompted by many separate interests and desires. A scholastic background of predominately scientific discipline and a long association with men of similar background, engaged in technical and scientific functions, has tended to subvert a social or human approach to problems involving people. A preoccupation with demonstrable logic and rationality as a basis for action in a cause and effect problem situation had evidentally developed. An analysis of the actions of others as mirrored in my personal values, morals and desires ensued. The need for inclusion of the liberal and social factors of reason and logic has become apparent.

This need, and the forthcoming assignment to a naval laboratory in an administrative billet suggested the importance of research into an effective philosophy for management of physical research workers.

In this research, the management objectives and problems are generally viewed from the character and needs of the individual creative worker. First-line management (the first level above this worker) is examined in light of these needs and characteristics; and a philosophical approach to management is proposed best to exploit the research worker's rare creative ability.

Acknowledgment and appreciation must be given to Dr. A. Rex Johnson who was primarily responsible for stimulating the broader and more gregarious outlook which, in large measure, prompted this thesis.

ROBERT G. IVERSON

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INTRODUCTION

Knowledge may be considered as an investment commodity or an inventory which can be used in a succeeding period. Present expenditures on research and development amount to about 4% of our national income and we are no longer in the age of mass production but, rather, in the age of massive engineering.[1] In some industries (like missiles and space products) millions of dollars have been devoted to systems where production costs are a relatively small percentage of the total expenditure.

The accelerating pace of scientific advancement may best be recognized by pointing out the historical progress of the speed of transportation. For the greater part of man's existence the maximum velocity of travel has been that of a man on foot (about 12 miles per hour). With the domestication of the horse, about 15,000 B.C., the upper limit was increased to about 35 miles per hour. By the end of the 19th century (some 35,000 years later) the railroad locomotive could travel up to 120 miles per hour. Only half a century later the phenomenal acceleration of technology provided military aircraft capable of sustained speeds of 700 miles per hour.[2] In the subsequent decade orbital velocities of 18,000 miles per hour have been achieved.

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[1] Paul O. Gaddis, "The Age of Massive Engineering," Harvard Business Review, Vol. 39, No. 1 (January - February 1961)

[2] Benjamin H. Williams, "The Importance of Research and Development to National Security," Military Review, Vol. XXIX, No. 11, p.10 (February 1950)

This thumbnail history of transportation velocity represents more than a million years, during most of which there was practically no change. The final tiny portion of the period has produced an exponential acceleration of maximum speed. Extrapolating this curve, or forecasting the advances which will result from projects already on their way to completion and the unpredictable possibility of unforeseen findings in basic research, points out the future requirements of scientific effort. In the physical science areas of energy conversion, communications, metals, materials and structures; chemical synthesis; and physiological and pharmaceutical fields similar intensive future demands will be made.

Man's ability to control his environment and adapt it to his use has, within the last few decades, been stimulated and accelerated by science. The race for national preeminence in industrial, economic and military technology has become one between scientific intellects. The future economic growth and defense posture of this nation are dependent upon this fund of scientific knowledge. Its source is ultimately limited by the time and skill of creative humans. It is consequently most vital that this limited resource be efficiently managed and wisely controlled.

Management and control of the mental output of gifted, creative men is a most difficult task; for how can one estimate the energy required, determine the level of skill, plan the sequence of tasks, or measure the effectiveness of the output as compared to other possible outputs? An administrator, skillful and perceptive enough to do these things, would have accomplished the greater portion of the creative research work. Because the administrator is dependent upon the research worker for a large portion of the

information which is necessary for planning and control, it appears vital that he work directly with and understand the research scientist; the way he thinks, the things he values, the problems he faces, and the reasons he works.

One of the major difficulties encountered in discussing research and development administration is the lack of a generally accepted terminology. To avoid this problem as much as possible, this paper will consistently use certain terms as they are defined below.

Research

> Research is theoretical analysis, exploration, and experimentation directed toward the increase of knowledge and thereby the power to control phenomena.

Basic, Pure, or Fundamental Research

> Basic Research is a search for facts and knowledge without reference to their application. The motivation for this research is scientific curiosity. It is a search for knowledge in a general field without reference to specific applications.

Applied Research

> Applied Research is a search for new knowledge directly applicable to a specific problem and the application of all existing knowledge to the practical solution of the problem.

Development

> Development is the extension of the findings and theories of a scientific or technical nature into practical application for experimental or demonstration purposes, including the construction and testing of experimental models or devices.[3]

These four definitions are quoted directly from G.W. Howard, Common Sense in Research and Development Management (New York: Vantage Press, 1955), p.5. Mr. Howard's definitions are a rephrasing of those adopted by the Industrial Research Institute in 1948 and the Joint Research and Development Board in 1947.

Design

Design is the process of translating germinal ideas for the solution of immediate and well defined problems into detailed plans for a material, device or process incorporating the results of basic and applied research.

Production Engineering

Production Engineering is the application of scientific and engineering knowledge and skills to the quantity manufacture of materials or devices of definite specifications evolved in development. It involves development and modification of equipment and processes required to maintain quality and efficiency in production.

Testing

Testing includes the determination of the properties and/or performance characteristics of a material device or process by controlled observation of the laboratory model or the completed item, for the purpose of determining whether it meets the original specifications and standards of performance.

Evaluation

Evaluation is the analysis and interpretation of test data to determine the usefulness of the completed material, device or process, and its suitability for adoption.

Technical Evaluation observes the item under controlled variations in laboratory conditions.

Operational Evaluation observes the item under actual operational environmental conditions.

Research Administration

Research Administration is the supervision of a research program through development of long-range plans, translation of research objectives into specific projects with appropriate priorities, delegation of responsibilities and tasks, management of personnel, funds, and facilities, coordination with other functional divisions and the maintenance of good internal and external relations, and the evaluation and reporting of research results.[4]

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[4] American Institute for Research, Critical Requirements for Research Personnel, (Pittsburgh, Pennsylvania, 1949).

The scientists have had the primary aim of controlling nature and enlarging knowledge without regard for any immediate practicable use. The engineer has been charged with the primary aim of controlling nature by converting new scientific principles into practical use. The scientist therefore, has traditionally been a thinker; the engineer a doer.

Early scientific discoveries came so far apart and industrial technology changed so slowly that engineering could follow at a lethargic pace. Between Faraday's discovery of electrical induction in 1831, and its translation by Edison and others into the first crude dynamos of 1860 to 1870, the time lapse allowed generations of engineers to be prepared to take over the improvements and production of the new mechanisms. The scientific explosion brought about by World War II had two leading aspects: a sharp increase in the volume and rate of scientific discoveries, hich had been growing exponentially since the last century; and a vast speeding up of the conversion of discovery to practical use. As an example, an atomic bomb was developed in less than seven years after the discovery of fission in 1939. This extreme acceleration of the use of scientific discovery found the conventional engineers unable and unequipped to keep up. They were swiftly left beyind by the physicists, chemists, mathematicians, astronomers, and even the biologists. The scientists' energies were required in the development and perfection of such devices as nuclear reactors, radars, rockets, computers, and many others.

Because of the present increasing demands to reduce the technological development period, the Massachusetts Institute of Technology has recently

made a bold decision to rewrite the whole School of Engineering curriculum to expand the scientific and research emphasis.[5] This decision is based upon the conviction that science and technology are now the key dynamics in growth and national position. In order that an engineer can bring forth desired new technologies, the very natures of which are essentially unknown during the period of his education, a more generalized scientific educational base is needed. Stronger science and theory backgrounds are needed to develop a creative potential.

The recent spectacular development of a bewildering array of modern machines and products is generally directly associated with science. The role of basic research and its fundamental relationship to progress in engineering and technology is generally inadequately understood. The increasing significance of science and technology in relation to public policy, both national and international, has enhanced the urgency of education of the public in the sciences. Scientific literacy on the part of the general public will not only provide intelligent democratic participation in national policy matters but will also augment the scientists' social stature. This recognition will serve to attract young and capable students into the scientific fields.

Management of scientific functions in industry and government requires a sensitive insight into the attitudes, values and thought processes of professional scientists. If the normal characteristics of this group can be categorized, they will provide a key to the formulation of a

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[5] Lawrence Lessing, "M.I.T. and the New Breed of Hairy Ears," Fortune, February, 1961. Vol. LXII, No.2, pp.128-135.

rational management philosophy. Such a formulation can be of vital importance in the efficient utilization of the limited scientific skill available, and can assist in attracting additional creative individuals into the scientific field.

PART I

THE DEVELOPMENT AND VITALITY OF CREATIVE RESEARCH

CHAPTER I

HISTORICAL PERSPECTIVE

Before discussing the essentials of managing research efforts, it will be useful to consider the evolution of research in its historical perspective.

The intellectual tumult of the Renaissance period removed much of the mysticism and religion from man's mind, and it became free to operate in logical and rational patterns. Leonardo da Vinci, one of the earliest philosophers of this period, was among the first to see clearly the unique power of the scientific method. He experimented by making observations under controlled conditions. He analyzed the results of these experiments and drew logical conclusions or hypotheses from the results of his findings. He was among the first to realize that if mathematical reasoning can be applied to observed phenomena greater certainty will be reached.

For the next 400 years, until about 1900, the scientist was usually a lone worker. In the first two centuries of this period he chose his subject of research from any sector of the broad frontier of nature's phenomena. If his curiosity dictated, he could and did investigate areas as divergent as astronomy and biology. He was absolutely free to make his choice of the subject of his research. Such unlimited freedom of choice provided great intellectual satisfaction and stimulation.

With the steady increase in volume and depth of scientific knowledge, there came divisions and later subdivisions of scientific knowledge. The natural philosopher became the astronomer, physicist, chemist, mathematician, or biologist; and later each of these devoted his attention to and did his research in a subdivision of his own area of science. This specialization was primarily a result of exponential growth of the body of knowledge. In order to push back the frontiers of the unknown it was necessary to concentrate an individual's attention on some limited segment of one frontier. In addition, the facilities necessary for research in many areas became more intricate, complex, and costly. Logistic and financial considerations supplemented the limitations of the intellect in forcing the scientist to narrow the segment of his broad scientific area. Within this restricted area, however, his freedom of choice persisted. This is an essential freedom of the scientist. The intellectual satisfactions to an inquiring mind, the necessary enthusiasms and zest for research adventure, can only be preserved by such a freedom.[6] In maintaining this freedom of choice, the distribution of research effort across the frontier of science is not rigidly planned. Many sectors receive scant attention while others are attacked in force. It is this uneven coverage of the boundaries of the unknown that provides the necessity and the opportunity for industry and government to enter basic research.

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[6] Dr. Mervin J. Kelly, "Basic Research", Handbook of Industrial Research Management, ed. Carl Heyel (New York: Reinhold Publishing Corp., 1959), p.140.

In the period between 1500 and 1700, the natural philosophers were men of inquiring minds from many professions. Artists, priests, men of law and business, and country gentlemen were all represented. The limited facilities required for research in those pioneering days made science a possible avocation for almost anyone endowed with the special talent and possessed of a curiosity about nature. The evolution of the university provided more acceptable environment for scientific investigation. Research was thereafter increasingly performed as a part of the professional activities of the teacher; and research as an avocation largely disappeared. A large portion of the new scientific knowledge of the past century was a result of the research programs of graduate school professors of science and their students. The requirement for the completion of a research project that adds some new element to scientific knowledge for the award of a Ph.D. of science added to the university participation in the field. The lone investigator almost disappeared in most areas of science. The growing size, complexity and cost of the tools of experimentation and the limitation of the field of knowledge of a single scientist provided the stimulus for the group or team approach to research. In this approach, an investigation is carried through by a large number of scientists supported by a variety of expert technicians. The very factors which precipitated the team effort in research demonstrate the essentiality of wise, inspiring, and judicious leadership of the team.

With all the present emphasis on teamwork, organization, and leadership it is of paramount importance that the research individual remain supreme. The creative ideas and concepts are ultimately born in the mind of

To the period between [illegible] and [illegible], the [illegible]

This all [illegible]

a single person. Insight into the future is through the eyes of the individual. Though the present environments are now organizational rather than monastic, the individuals continue to be the most important element in the productivity of research. The results of research depend primarily upon the individuals of the professional staff. The creative quality of their minds, the depth and scope of their scientific training and experiences, their courage and tenacity, their intellectual integrity are the primary assets of any research program.

The quality of a research organization is therefore ultimately dependent upon the composition of the professional staff. The management of the organization is not only responsible for the initial selection of the potentially productive scientists, but is also charged with the proper development of their potentials.

CHAPTER II

NATIONAL PROGRESS THROUGH SCIENCE

The Need

> Basic research leads to new knowledge. It provides scientific capital. It creates the fund from which the practical applications of knowledge must be drawn . . . . Today, it is truer than ever that research is the pacemaker of progress.[7]

The last decade of the United States history has seen the universal acceptance of the primary importance of economic growth. National economic growth is essential in terms both of our commitments as a free people and of our dedication to the goal of full employment. We need expanded output to provide military security and to maintain our programs of foreign aid. To illustrate this free democratic society as an example to other nations it is necessary to improve the living standards of our growing population, and more particularly to reduce the remaining pockets of ignorance, poverty and ill health.

National economic growth is, in the long run, dependent upon the expansion of private demands and a rise in disposable personal income. Government spending or fiscal policies and government monetary policies have both direct temporary effects and continuing catalystic effects on national economic growth. The significant expansion in business outlays for plant and equipment may be accelerated for short periods by government policies, but the

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[7] Alan T. Waterman, "The National Science Foundation", Impact of Science on Society, (Place de Fontenoy, Paris - 7, France: United Nations Educational Scientific and Cultural Organization, 1961), Vol. XI, No.4.

continued expansion is dependent upon increasing private demands and disposable personal income.

The primary source of our potential output and its growth is the number of people available for employment, the number of hours they are able or wish to work, and the qualifications and skills they bring to the market place. Current and future levels of output are therefore dependent upon the health, general education, incentives, mobility, and specific occupational skills of the present and future workers. A secondary, but extremely important ingredient in the nation's productive capacities is the current state and rate of progress of technology. This source of potential growth stems, of course, from the capabilities and employment of the available workers. The nation's technological status includes not merely the familiar factors of knowledge in scientific, engineering, and mechanical fields, but also the whole range of managerial and organizational competence, which effects the efficiency with which economic processes are operated. A third main source of potential growth is an increase in the efficiency with which resources, both domestic and foreign, are allocated to different economic purposes.[8] This dependence of productive potential upon efficiency may be considered also to stem from the capabilities and employment of the available workers.

From the above it would follow that the national economic growth rate can be effectively influenced by creativity and innovation. The national investment in research and technological development will have

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[8] U.S., President, 1961 -- (Kennedy), January 1962 Economic Report of the President, (Washington: U.S. Government Printing Office, 1962).

direct and lasting effects in all three of the main sources of potential growth. The skill, health, education, mobility and incentive of the working force will be directly and indirectly influenced. The progress of our overall technological status will be directly affected. The efficiency with which resources are utilized will also be directly influenced.

The Present Effort

Manpower is the most vital and critical of all our natural resources. It is generally agreed that this nation, with but 6½ per cent of the world's population, is producing more than 50 per cent of the world's output of goods and services.[9] The ability of the average United States worker to produce more than fourteen times the goods and services of the average worker in the rest of the world is a startling example of the efficient use of limited resources. The natural, physical resources of this country have, of course, had some influence upon this productive ability. Our relative material advantages in the last century were much more significant than those of today. The social and economic environment has provided a major and lasting advantage to the growth of efficient production. Research, development and invention have provided a primary enabling influence for our rapid economic growth. Dr. William A. Hamor, the Senior Director of Research, Mellon Institute typified the research investment principle in his statement: "Today is the outcome of yesterday's research and invention; and one can perceive the future unrolling in the technology of the present."

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[9] William K. Bassett, Civilian Manpower Assistant, Office of the Comptroller, Department of the Navy, Washington, D.C., "Manpower," Lecture given before the George Washington University Navy Financial Management Course, Washington, D.C., February 27, 1962.

The past several decades of the United States economy are characterized by a phenomenal growth of research and development expenditures. The United States is today spending more money for research in one year than the total research and development expenditure from 1776 to 1933.[10] The most rapid expansion of these activities has been experienced since the beginning of World War II. In 1940 a total of less than one-half billion dollars was spent. By 1945 this figure had grown three fold, but even 1945 outlays are dwarfed by the $10.5 billion total which was spent in 1960.[11] The President in his 1962 Economic Report has proposed an increase in the federal expenditures in fiscal 1963 for research and development programs to a total of 12.4 billion dollars.[12] Figure 1 traces the expansion of research and development expenditures since 1953. The federal government supported effort has increased from 39% of the total in 1953 to about 58% in 1960. A nearly threefold increase in the total research performed in industry and supported by both private and governmental funds has occurred over the same period. The relative importance of these sums is best evaluated by comparing the rate of growth of research expenditures with the growth rate of the whole United States economy. Figure 2 establishes the relationship of research outlays to Gross National Product since 1925. In the period from 1925 to 1955, while the Gross National Product was increasing at an average annual rate of 3 per cent, research outlays experienced a 10 to 12 per cent annual rate of growth.

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[10] James Brian Quinn, Yardsticks for Industrial Research (New York: The Ronald Press Company, 1959), p.5.

[11] National Science Foundation, Annual Report of the Joint Economic Committee, Congress of the United States on the January 1962 Economic Report of the President, 87th Congress, 2nd Session, Joint Committee Print (Washington: U.S. Government Printing Office, March 6, 1962), p.74.

[12] Ibid.

The last five years has seen an even more startling emphasis on research, resulting primarily from increased governmental expenditures in the field.

The federal government now supports about two-thirds of the research and development activities of the nation.[13] The Department of Defense spends the lion's share of federal research funds, virtually all of which go to a very small number of prime contractors. The ten largest contractors accounted for nearly 57 per cent of the total Department of Defense research outlays, the largest twenty for some 73 per cent, and the top twenty-five for approximately 77 per cent. Moreover, in distributing its research and development funds, the federal government concentrates on a very few industries. In 1960, more than three-fourths of the total spent by the federal government went to just two industries -- aircraft and parts, and electrical equipment and communications. When private funds are considered, these two industries, plus chemicals and allied products, received approximately 80 per cent of all research and development funds spent in industry in 1960.[14]

This high degree of concentration of research and development funds in a small number of firms in a limited number of industries emphasizes the necessity for efficient central management of this function. This disproportionate share of total industrial research centered in the largest corporations may foreshadow a greater concentration of economic power in these firms in the future. These research programs themselves are basic factors in the last five years [illegible] research, resulting primarily from [illegible] in the fields.

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[13] R.H. Ewell, "The Role of Research in Economic Growth," Chemical and Engineering News, (July 18, 1955), p.2981.

[14] U.S. Congress, Joint Economic Committee, Annual Report of the Joint Economic Committee Congress of the United States on the January 1962 Economic Report of the President, 87th Congress, 2nd Session, Joint Committee Print (Washington: U.S. Government Printing Office, March 6, 1962), pp.74-76.

The federal government also finances about two-thirds of the research and development activities of the nation.[13] The Department of Defense provides the largest share of federal research funds, [illegible] of which go to [illegible] of private [illegible]. [illegible] accounts for nearly [illegible] per cent of the total Department of Defense research [illegible], the [illegible] for [illegible] per cent, and the [illegible] in the approximately [illegible] per cent. Moreover, in distributing the research and development funds, the federal government concentrates [illegible] for [illegible] in 1961, more than three-fourths of the total spent by the federal government went to [illegible] manufacturers of aircraft and parts, and electrical equipment and communication. These [illegible] firms [illegible] industries [illegible] per cent of the research and development funds spent in industry in 1961.[14]

This high degree of concentration of research and development funds in a small number of firms in a limited number of industries represents [illegible] [illegible] of this [illegible]. This [illegible] [illegible] in their share of the market. [illegible] the development and expansion of the business enterprise economy. This concentration may mean that in the future an increasing share of anticipated improved technologies and new product lines will be introduced by the industrial giants. Attention to some of the long run impacts of research and development policies on the future of competitive enterprise are necessary.[15]

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[13] [illegible], "The Role of Research in Economic Growth," [illegible], (1963), [illegible].

[14] U.S. Congress, Joint Economic Committee, [illegible] of the United States [illegible].

Furthermore, most of the research and development funds are expended on applied research in the sciences and in engineering. Only a very small per cent is spent on basic research. In 1960, for example, only about 8 per cent of the $10.5 billion spent on research and development, or $382 million, was allotted to basic research.[16] This emphasis on the search for new knowledge directly applicable to a practical solution of a specific problem again emphasizes the necessity for efficient management.

The idea of fostering and encouraging basic research for its own sake, and of supporting such research with federal government funds, did not arise until World War II. Traditionally, universities and other private research organizations had provided needed research tools from their own funds or from funds available from state or local sources. Today, however, the cost of such major equipment as nuclear reactors, high-energy particle accelerators, high speed computers, and radio and optical telescopes is too great to be met from such local resources; or even from the combined resources of several institutions. After a study of the situation, the National Science Foundation recommended that federal support for the needed facilities would be necessary

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[15] Herbert Brownell, Attorney General's Report of November 9, 1956, "Review of Voluntary Agreements Program Under the Defense Production Act and Related Material" (Senate Banking and Currency Committee), pp.17-18.

[16] U.S. Congress, Joint Economic Committee, loc. cit.

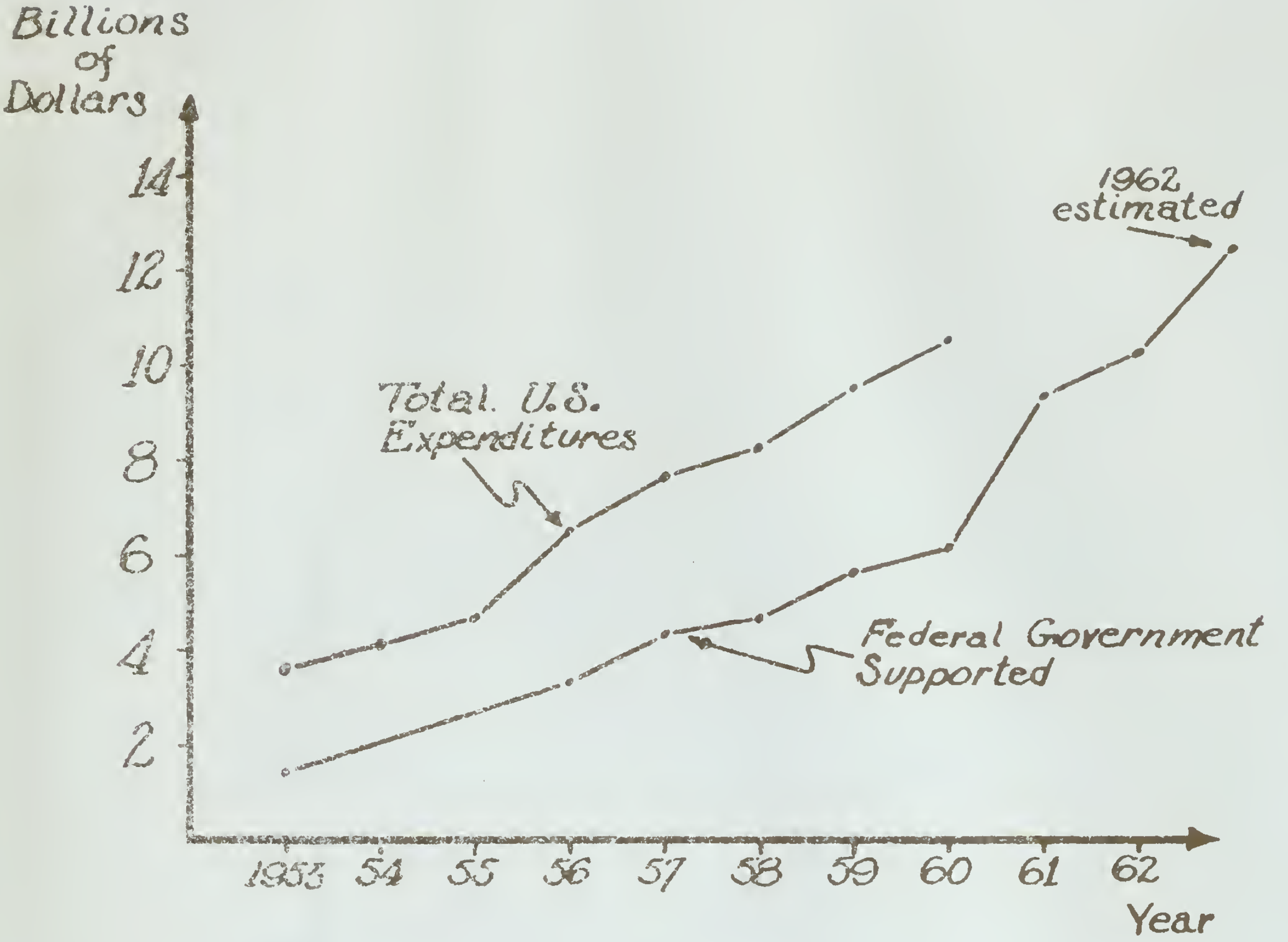

Fig. 1. -- U.S. Trends in funds expended for industrial research, experimentation and technological development -- by source of funds, 1953 to 1961.

Source: National Science Foundation, quoted in Annual Report of the Joint Economic Committee, Congress of the United States on the January 1962 Economic Report of the President, 87th Congress, 2nd Session, Joint Committee Print (Washington: U.S. Government Printing Office, March 6, 1962), p.74.

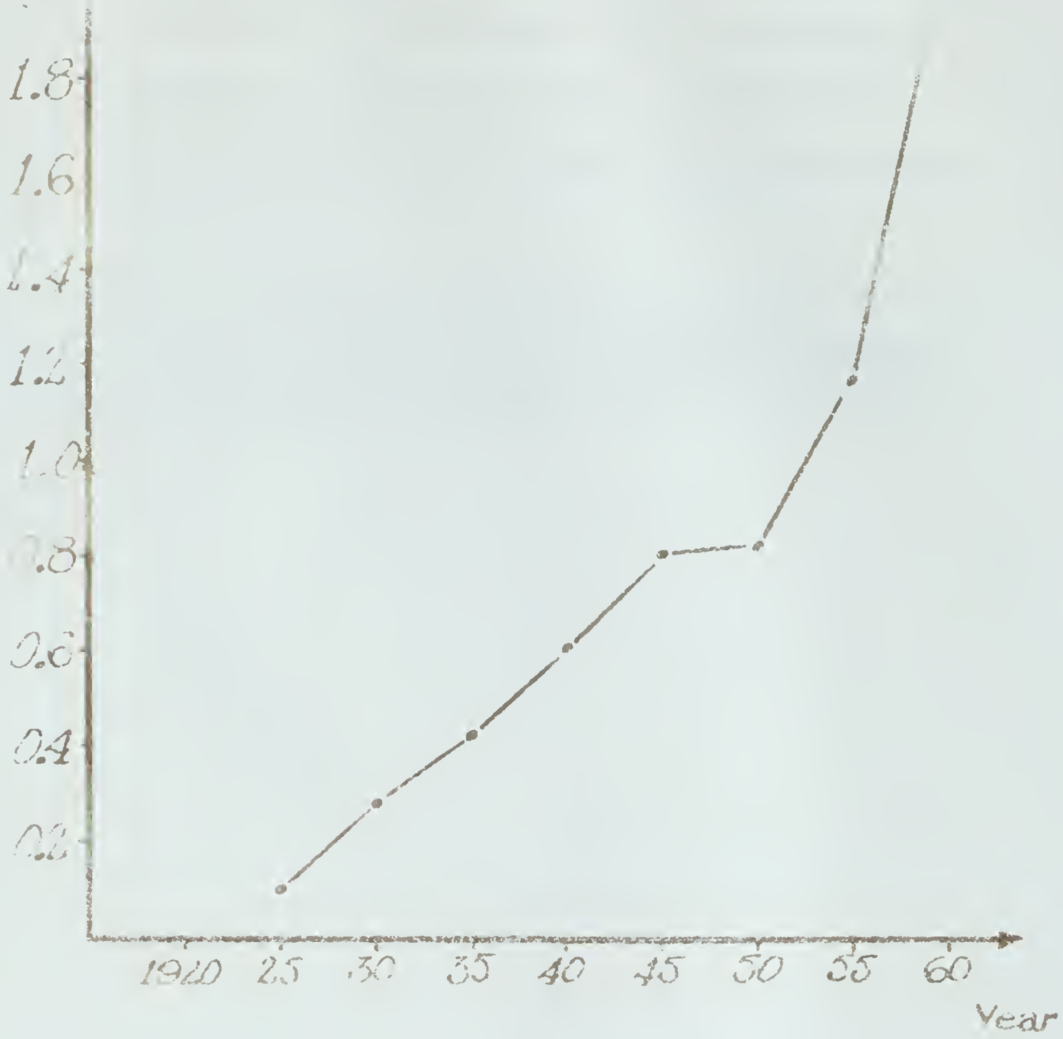

Fig. 2. -- Total U.S. research and development expenditure as a per cent of gross national product.

Source: R.H. Ewell, "The Role of Research in Economic Growth," Chemical and Engineering News, (July 18, 1955), p.2981.

to insure satisfactory advancement of science in this nation.[17] University nuclear research equipment and computing facilities, oceanographic research vessels, biological field stations, the National Center for Atmospheric Research, the National Radio Astronomy Observatory, and the Kitt Peak National Observatory are examples of new facilities being funded through federal support.

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[17] Alan T. Waterman, "The National Science Foundation", Impact of Science on Society, (Place de Fontenoy, Paris - 7, France: United Nations Educational Scientific and Cultural Organization, 1961), Vol XI, No.4.

PART II

THE SCIENTIFIC APPROACH

CHAPTER III

IDEA EVOLUTION

How are scientific ideas evolved? Only the practicing scientist can understand the training and practice, discipline and method, strategy and imagination called upon in the supreme execution of this function. The central aims of all sciences are concerned with a search for understanding. The desire is to make the course of nature not just predictable but also intelligible.[18] This has necessitated a search for rational patterns of connections in terms of which sense can be made of the flux of natural events.

Scientists are rightly suspicious of preconceived ideas and pride themselves on coming to nature in a spirit of objectivity. They do however, by necessity, design experiments around preformed concepts. These must not be prejudiced beliefs, and they must be suitably tenative and subject to reshaping in the light of the ensuing experiments. A proper development of a scientific idea will come only if the researcher is able and prepared to unthink the original concepts.

When questioned about his youth at 31, Harold Brown, Deputy Director of the Lawrence Radiation Laboratory, Livermore, California, said, "Obsolescence of a scientist's mind is not due to a slowing down. Rather it is a matter of attitudes hardening and of becoming conservative".[19]

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[18] Stephen E. Toulmin, Foresight and Understanding, (Indiana University Press, 1961), p.13.

[19] Grace and Fred M. Hechinger, "X-Ray of the Scientific Mind", The New York Times Magazine, (October 18, 1959), Section VI, p.27.

When today's non-scientist considers some of the historical scientific theories in light of what is "known" in the present, a chaotic, illogical, poorly documented, philosophical, and elementary explaination of nature is viewed. Today's student learns about, and views nature in light of the present accepted scientific theories. To become a creative research worker he must be able to deviate from these theories and view scientific thought as a developing body of ideas and techniques. These ideas of science are continually evolving in the changing intellectual and social environment.

To evaluate the difficulty of any scientific advancement, the mental energy and ability required, one must examine the development in light of the intellectual environment which existed before the advancement. Only in this context can one give the ideas and investigations their proper merit. Scientific progress comes about only through the critical application of creative intellect to the problems that arise at one time, in light of the evidence and the ideas which are then open to consideration. To foresee a possibility in any detail is halfway to its creation. To estimate the difficulty of the scientific advancement consideration must be given to the original conception of the possibility.

Learning does not confer the power to achieve new scientific knowledge and understanding, or even to appreciate it when it is offered by others. Ability to achieve new scientific knowledge and understanding is not even conferred by an infinite capacity of patience and industry. What does appear essential for real achievement in scientific research is a combination of qualities, much commoner than genius. A clarity of mind, a combination of imagination and caution, of receptivity and scepticism, of patience and

thoroughness, an ability to finalize, an intellectual honesty, and most importantly, a love of discovery are the primary elements of this combination.[20]

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[20] Paul Freedman, The Principles of Scientific Research, (Washington, D.C.: Public Affairs Press, 1950), pp.74-76.

CHAPTER IV

THE PATH OF SEARCH

More than half of all significant technological inventions during the last century has resulted from the work of individuals. Most of the inventions have been the outcome of chance rather than goal-directed efforts. One of Britain's leading scientists has noted that all inspiration and all new ideas come from some one individual.[21] The intensive studies of Professor John Jewkes and his colleagues indicate that where work is done in company laboratories, the small team seems more effective than the large one; and that it is usually a particular individual who supplies the "big jump" in thinking which is the very basis of the creative process.[22] These studies point out that the careful organization and close supervision of creative effort seem to act as deterrents rather than aids.

The essence of research and discovery is their focus upon the unknown. The research scientist, like an artist, tends to demand the right to decide how best in his own way to approach tasks, to use talents, to create procedures. To invade this privacy to an extent greater than that which is absolutely necessary is to defeat the scientific spirit. To try to direct investigations from above, to highly organize research institutions, to try to

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[21] Sir Alexander Fleck, Chairman, Imperial Chemicals Industries, "The Pressure of Technical Change," Vitality in Administration, (London: George Allen & Unwin, 1957), p.38.

[22] John Jewkes, David Sawers, and Richard Stillerman, The Sources of Invention, (New York: The Macmillan Company, 1958), p.9.

reduce invention into a systematic routine would serve to stifle invention along with all other forms of initiative.

William H. Whyte's conclusions in The Organization Man, indicate that most productive laboratories are those where independence is encouraged, individual differences are tolerated, supervision is casual, immediate financial gain is of secondary importance, temperament is respected, and there is no artificial attempt to instill the feeling of "belonging to the team".[23]

Enthusiasm is the key to a scientist's character. When a very individualistic but gifted researcher is used in a group effort, the team must be tailored around him. Teamwork, despite the advantage of exploiting the interplay of creative thinking, runs into road blocks of human relations. The emergence of group science has not turned scientists into cogs of a great machine.[24] Rather, it can supply the stimulation and motivation for the individual's creative work.

Before attempting to analyze the management functions and techniques which will best enhance the development of the scientist's productive potentials it is important to look into the functional divisions of a research effort and into the attitudes of the men in the scientific profession.

The critical requirements of a creative effort can be broken down into terms of behavior necessary to cope with the sequential stages of research.[25] The initial area of problem definition and hypotheses formulation stresses

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[23] William H. Whyte, Jr., The Organization Man, (New York: Simon & Schuster, 1956), p.403.

[24] Grace and Fred M. Hechinger, "X-Ray of the Scientific Mind", The New York Times Magazine, (October 18, 1959), Sect. VI, p.28.

[25] American Institute for Research, Critical Requirements for Research Personnel, (Pittsburgh, Pennsylvania, 1949).

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William H. Whyte's commentary on *The Organization Man*, [illegible]

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[illegible][2] [illegible]

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[1] William H. Whyte, Jr., *The Organization Man*, [illegible]

[2] [illegible] *The New York Times Magazine*, [illegible]

[3] [illegible]

a creative and imaginative behavior and emphasizes an alertness to deviate from the usual problem limitation practice. This area undoubtedly requires the most brilliant and capable research men. One man of superior intelligence, unusual dedication and creativity will have a much greater value than several at the median value in this area.

The planning and designing of the investigation is the next usual step of research. This area stresses setting up a logical and systematic sequence of steps concerning the technical investigation of the selected problem or hypothesis. A before-the-fact evaluation of the relative importance of factors in the problem is essential to efficient planning of the investigation. The control and range of variation of the important parameters and the accuracy and volume of data to be collected are important aspects of this step.

Setting up and conducting the investigation is the next usual step. The emphasis here is on general technical competence in conducting the active phases of a research study as it has been planned. Ingenuity and resourcefulness in devising, choosing, or modifying techniques, materials, or procedures to fulfill the plan are necessary. Awareness of the need for checking details of seemingly insignificant occurrences is also required.

The interpretation of the research results demands a logical and deductive ability. This stage includes the consideration of all the data or phenomena observed, the effect of the experimental design on the data, and the final conclusions as to the validity of the results. An insight into the implications of the findings on application to related work and the extension of these conclusions from the specific to the more general applications is included in the interpreting or analyzing step.

In preparing the research report the ability to describe in a clear, precise and understandable fashion is a primary requisite. The report should state only those facts and details necessary to understand the work, explain the problem background, the relation of the problem to other work and the meaning of the results.

In order that any or all of these steps can be efficiently and successfully completed the functions of administration must be present throughout the process. These enabling functions include the selecting, training and placing of personnel; planning and coordinating the work of groups; the liaison necessary between working groups; and the promotion of the acceptance of organizational responsibility and the attendant personal responsibilities.

When we look at what a scientist does we find that the activity is directed toward abstraction from the specific environmental data of his research to the highest possible degree of generalization. It follows that in basic science there is a very low degree of environmental coupling. The greater the basic scientific importance, the broader the generalization. It is also significant that the connection of the scientist's activities to deadlines is highly elastic. There is therefor also a low degree of time coupling in basic scientific work.

A higher degree of environment coupling and a higher degree of time coupling are found in engineering activities. The engineer is not interested in a theory as an abstraction. He is concerned with its particularization to the development of a specific design, at a specific place, to meet specific requirements and to be completed by a scheduled deadline. The function of

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In order that any or all of these steps may be effectively and [illegible] throughout the process. [illegible] responsibilities.

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engineering is the design or planning for solutions of particular problems. The urgency of these problems does not allow the engineer to defer his progress until the generalized knowledge has been fully developed by scientific inquiry. There is a limit to the engineering progress that can be expected beyond the basic scientific foundation. Until scientific inquiry has built a foundation under the engineering steps already taken, further engineering progress is increasingly inhibited.

The usual terminal product of a basic scientific inquiry is a published communication of results to the scientific community at large. Engineering effort, on the other hand, yields an implemented plan or design. Because the engineer's product is directly useable by management and because he has a higher degree of environmental and time coupling the mutual interaction between the engineer and the management function is more demanding and more direct than the interaction between the scientist and management.

The basic scientist often looks to the engineering field for stimulation. The steam engines designed by James Watt were already in commercial use when the beginnings of heat engine theory were formulated by Carnot. Accomplished engineering fact has provided powerful stimulation for scientific research effort. There is a similar tendency for mutual interaction of engineering personnel with management to stimulate the necessary scientific developments.

Both the executive and the engineer must be able to recognize and weigh the possible trade-off of time, effort, and funds against assurance or rigor. The basic scientist, because of the generalized nature of his product, tends to be most conservative. He is willing to expend large

amounts of time and effort to gain assurance and rigor. The engineer is willing to work with less rigor but attempts to buy some secondary assurance with "safety factors". The executive is more aggressive and is often willing to act without a safety factor.

The basic research scientist strives for generalizations which explain nature. The applied researcher strives to particularize to resolve specific problems. The application of basic information or theory to immediate, practical problems is limited by two major factors.

First, the rapid and exponential increase in the fund of knowledge raises the problem of allotting sufficient time to keep up with the information output. Second, the approach to increasing efficiency through specialization imposes an additional burden on communications and coordination. Related to this second factor and increasing the coordinative burden is the traditional academic discipline boundaries. Research boundaries, defined by practical research problems, have little correspondence with the academic boundaries. The research worker seeking to assemble the basic research background bearing on an immediate and specific practical problem must search in a number of traditional disciplines. The conversion of the theoretical abstractions and generalizations to real problems in concrete environments is thereby made more difficult. The barrier to this conversion comes about because the knowledge of basic research is not structured for use in the applied research field. The social sciences have complained about this barrier.[26] It is also, however, an important problem in physical, applied research.

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[26] Harold Guetzkow, "Conversion Barriers in Using the Social Sciences," _Administrative Quarterly_, IV (June, 1959), p.71.

The process of basic research utilization is then a problem of applying the previously formulated concepts and their inter-relations. These concepts or theories are abstract and general because they have been formulated and tested to explain nature. The formulation considers a limited number of variables and a set of mathematical relationships are developed which apply to the interrelation of the chosen variables. The immediate practical requirement becomes a problem when the actual environmental variables do not coincide with the limited variables of the basic research theory. The overlapping of basic theories, and the overlapping of traditional academic disciplines which apply on a specific practical problem point out the difficulty of coordinating scientific knowledge and experience on applied research.

Though a single individual can conceive the approach to an applied research problem, he usually must rely on men experienced and knowledgeable in the allied disciplines for the detailed, specialized knowledge in these other traditional fields.

The dividing lines between research and engineering in some industries have all but disappeared. There is no pause in the transition from basic research to engineering development; nor from engineering development to manufacture. The so-called "engineering costs" often exceed the cost of production. The missile and sometimes the jet aircraft industries are examples of this type of cost distribution. In many companies, technical personnel are almost as numerous as production personnel. This distribution or allocation of people is typical of the highly technical industries in ascendancy today. The speed of obsolescence has increased to the point where advances in miniaturization are so swift that miniature electronic designs do

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not get into real production before they are succeeded by microminiature designs and microminiature requirements.[27]

In order to provide the maximum usage of the creative scientist or engineer under these demanding circumstances it is necessary incidentally to increase the use of sub-professional technicians. Further, because of the compressed time requirements, it is necessary to analyze the skills or abilities necessary to meet the technical function requirements. The technical functions are thereby linked to multiple disciplines. The complexity of today's technology generally requires groups of disciplines, not only for the basic research phase, but also to provide a contimuum between that phase and the development and production phases.

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[27] Maj. Gen. Leslie E. Simon (Ret.), "The Spectrum Theory of Organizing Research and Engineering", Industrial Research, Vol 3, No. 5 (November 1961), pp. 52-61.

PART III

INGENUITY AND CREATIVITY

CHAPTER V

CREATIVE SATISFACTION

Rear Admiral Luis de Florez, USNR (Ret.), an inventor, engineer, and pilot proposes that the quality of ingenuity is most important to national and world success. He characterizes ingenuity as inventiveness, resourcefulness, and the ability to improvise.[28] The definition and connotation are very similar to those of the word "creativity" used in this thesis. Ingenuity, or creativity, tends to be associated primarily with science and technology. Actually, these characteristics are major ingredients of success in every human activity. We recognize ingenuity in medicine, politics and mathematics, in business, the law, the arts and music; in international relations, in wars and in peacetime diplomacy. Neither ingenuity nor creativity are easy to define. We recognize the characteristic or its lack on every hand. It appears to be an extraordinary combination of imagination and nonconformity which provides a means of attaining an objective, usually despite inadequate resources or adverse circumstances. It is not always possible to identify the ingredients of motivation which lead to the development or application of this quality. Certainly necessity is a spur. Man's historical ability to meet demands and his natural tendency to try to outdo his fellow man have been prime motivations. This competitive spirit can be nurtured only through rewards for successful application of a creative skill. A person who is

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[28] Luis de Florez, "Qualities of Victory - Part 4: Ingenuity", Nation's Business, Vol. 50, No. 2 (February 1962), pp.57 - 63.

seized by this drive -- like an artist -- seems more interested in what he is doing than in the social status or financial rewards he may derive. The achievement motive is considered by some to be an elementary ego need.[29] The attributes which are commonly called ambition, desire for accomplishment, will-to-power, desire for prestige, and the desire to overcome obstacles may all be prompted by this ego need alone or from the fusion of this and other needs.

People with high achievement motivation excel in various ways. They work harder at laboratory tasks, learn faster, and do better academic work even though their IQ's are no higher than the average. They work better under pressure even though no special incentives are introduced. They are self-reliant and more resistant to social pressures. They want to set their own tasks and establish their own quotas. They are inventive and are not easily discouraged. They are nonconformists. They are self-disciplined. And finally, they are creative. Certainly these attributes are the basis for success of any scientific researcher.[30]

In order that creative enterprise can succeed, four basic components are necessary. First, there must be an incentive or motivation to invent or innovate and to accept new situations. Second, there must be an idea, something new and positive emerging from a creative mind. Third, both of these components depend upon innovative people. And fourth, the administrative and management functions must encourage rather than obstruct invention and initiative.

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[29] Henry A. Murray, "Types of Human Needs", Studies in Motivation, ed. D.C. McClelland (New York: Appleton-Century-Crofts, 1953).

[30] J.W. Atkinson, Motives in Fantasy, Action, and Society, (Princeton: D. Van Nostrad Company, 1958)

What causes people to want to start something new, to take up a challenge, to respond to a change? Only after these questions have been analyzed and general answers compiled can one hope to determine how to get research people to work together harmoniously without limiting their freedom and their individuality.

People who are self-starters, discoverers, innovators, and capable of working without the prod of artificial stimulants have what is called an achievement motive. This motive is apparently influenced by both environment and individual personality, with the major role played by the latter. This theory of motivation has been validated by a number of clinical tests.[31] It tends to explain many of the aspects of motivation which have heretofore been poorly understood.

This theory indicates that the amount of energy a person is willing to expend depends more on his own inner concerns and desires than on stimulation from the outside. The achievement motive involves character, temperament, and other qualitative factors as well as ability, intelligence, and rationality.

Perseverance is another primarily required trait for research workers. In time of crisis, when occasion demands it, most Americans are willing to lay aside the comforts of life and resolutely pitch into a job. While these people are generally able to summon up their strength for one decisive battle and then hope to enjoy the fruits of victory, few are able or willing to make the same sacrifices over a prolonged period for a worthy goal. The changes brought about by the present urban industrial society has resulted in a

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[31] David C. McClelland, Community Development and the Nature of Human Motivation, (Cambridge, Massachusetts: Associates for International Research, Inc., 1957).

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separation of men's labor and their life. The office and factory have been divorced from the home and the community. The job is not a part of life, not worth doing well for its own sake, but is a means of earning some level of comfort outside it. The less time and energy spent at this necessary "evil", the better.

These people cannot be good scientific researchers. The creative advances depend on the perseverence of the men who conceive the ideas and work to convert them to valid or useable theorums and inventions. Eli Whitney had achieved fame, but no fortune, through his invention of the cotton gin by the time he was 33. Thereafter he had his most productive idea -- the simplification of the production process and the repair function by precisely duplicate part fabrication. He attempted to apply this concept to musket production after obtaining a government contract for 10,000 units. The task proved far more formidable than he had visualized. He worked for about eight years, made no profit, and received little recognition for conceiving or developing the idea of mass production and repair by part replacement. Perseverence and personal drive had seen him through the opening of the most important channel to American industrial development.

These qualities are typical of the good research worker today. Fitting problems, good ideas, and successful experimentation cannot be scheduled or expressed in man's brain hours. Neither the scientist nor the explorer can analyze and synthesize accurately the problems of an unknown environment. Neither should consider their efforts a failure just because the intended goal proved unattainable. The effort of reaching for the objective makes future attempts more probable of success.

If capable scientific researchers are endowed with unusual perseverence and personal drive continuing formal supervision is desirable only to the minimum extent necessary to make their goal coincident with that of management.

To provide an incentive for human improvement the principle of equal reward for equal effort is universally accepted. The rewards available however, should be tied to the desires of the possible recipients. Since a creative person gets more satisfaction out of the sense of successful struggle and accomplishment than from pecuniary gain, the rewards available to him should be aimed at recognition, commendation, respect and prestige.

CHAPTER VI

DRIVES AND MOTIVATIONS

The greatest reimbursement a scientist can obtain is the opportunity to become accepted as an expert in his field of specialization. This is one of his primary satisfactions.[32]

Any reward, to be an effective motivating influence, must be thought to be valuable in the eyes of the recipient. Many successful but unheralded scientists are driven by relatively little reward other than the esteem of their fellow scientists and their own self-satisfaction for their accomplishments.

Scientific creativity has lived, thrived, and been highly productive in the academic community for more than a century. An attempt by industry or government to recreate, as nearly as practicable, this environment and its rewards would appear to be a sound approach. This has been a major objective of Bell Telephone Laboratories for more than twenty years. General Electric, on the other hand, believes that an "ivory tower" approach to research will not provide an effective atmosphere for integrated system design or multi-disciplinary problems. Though General Electric is a decentralized company, they prefer a business-like environment in what they

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[32] Seymour Freedgood, "Building an Effective Research Organization", Steel, (August 1956), p.54.

term a "living laboratory".[33] Under this concept the research team's attention is focused upon specific, clearly defined, existent problems. Control is exercised to concentrate the creative contributions in the areas most needing improvement.

The challenge of building a productive and enduring research organization includes the determination of the type of personnel, the organization, the housing, facilities, and other environmental elements which are suitable. The composition of the professional staff is the most important single element in determining the long-run productivity of a research organization.

The creative research worker need not be enticed to do research. If he is any good he wants to do research in spite of administrative restrictions. How can an administrator provide the incentives so that the research worker will continue to effectively expend his energy?

Undisturbed time is a must for a truly creative research worker. A portion of this time should be allotted for problems of personal interest. Interruptions and demands for administrative duties should be minimized. One of the incentives which an administrator can help to provide the research worker is therefore the time for research; both the time for the assigned problems and allied and personal interest problems.

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[33] H. Ford Dickie, "Integrated Systems Planning at G.E." Management Control Systems, ed. Donald G. Malcom, Alan J. Rowe and Lorimer F. McConnell (New York: John Wiley & Sons, Inc., 1960) Section IV, Chapter A. p.142.

An opportunity for advanced training is important to the research worker, particularly the younger investigator. The training can serve to broaden him or take his interests into related sciences, or it can act to intensify his knowledge and skill in his chosen field. The latter may make him a better operator in a particular field, and the former may help to uncover new facts, so many of which lie in the unexplored areas between disciplines. To provide this incentive raises additional requirements of available time.

The opportunity to attend professional group meetings is another effective incentive which also raises the question of time requirements. The scientist's desire for the social-scientific symposium stems from the needs for training, prestige, and recognition. As necessary, assistants and equipment are important incentives. They provide more time for advanced thinking as long as administrative duties are not increased significantly. Security as provided by retirement plans and current financial rewards also provide some motivation for this creative group.

In order to provide the enabling functions of administration an understanding of the attitudes and motivations of the scientists as a group is necessary. To stimulate the creative output of a group whose general functions are described above it is vital to generalize their personal attitudes and goals. A recent study[34] was conducted to develop, for Presidential consideration, recommendations to improve personnel management of scientists

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[34] Committee on Engineers and Scientists for Federal Government Programs, Survey of Attitudes of Scientists and Engineers in Government and Industry, (Washington: U.S. Government Printing Office, April 1957).

and engineers in the federal service. This study analyzed the results of comprehensive questionnaires and interviews with governmental and industrial scientists and engineers. More than 17,000 government respondents and more than 3,000 industrial respondents participated. One portion of the questionnaire was designed to weigh the factors which contribute to the scientist's or engineer's job satisfaction. Table 1 shows a listing of these factors, the relative weights, and standard deviations for the government and industrial respondents.

To generalize the results of this survey, it would appear that the professional drive of this group far outweighs the occupation-oriented drive of other groups. A very high percentage of the important motivating factors relate to professional freedom, personal accomplishment and recognition. The desires for financial remuneration, security and informal associations appear to be suppressed in comparison to other occupations. A relatively nongregarious, nonmaterialistic, nonsocial, introversive professional would embody the essential characteristics documented by this survey. If a study such as this were expanded to include all the categories of professions, disciplines and occupations, correlating factors between the scientist and engineer group, and each other grouping could be determined. It is postulated that the groups exhibiting the greatest reciprocity to the scientist-engineer group would be other creative groups. The artists who are concerned with the design of beauty in accordance with aesthetic principles, and the philosophers who are concerned with the facts and principles of moral wisdom and ethical behavior, would yield survey results whose correlation factors with Table 1 would be near unity. It is impressive to visualize the difficulties one would

TABLE 1

FACTORS CONTRIBUTING TO SCIENTIST'S AND ENGINEER'S JOB SATISFACTION[a]

Factor	Government Mean	Industry Mean	Government Standard Deviation	Industry Standard Deviation
Interest potential of work .	1.76	1.78	0.88	0.86
Integrity of management. . .	1.89	1.82	0.96	0.89
Opportunity to discover and do creative work	2.03	2.29	0.99	1.04
Opportunity to move up in the organization	2.15	2.12	0.97	0.97
Calibre of supervision . . .	2.17	2.13	0.98	0.92
Pay and living conditions. .	2.31	2.25	0.84	0.80
Opportunity to feel a part of the organization. . . .	2.41	2.34	1.07	1.02
Opportunity to contribute to basic scientific knowledge	2.40	3.01	1.07	1.16
Professional recognition . .	2.45	2.55	1.08	1.06
Physical facilities for research	2.44	2.64	0.94	0.98
Security of employment . . .	2.49	2.56	1.03	1.03
Congeniality of associates .	2.59	2.54	1.00	0.94
Social value of work	2.81	3.18	1.13	1.11

[a] Source: Committee on Engineers and Scientists for Federal Government Programs, Survey of Attitudes of Scientists and Engineers in Government and Industry, (Washington: U.S. Government Printing Office, April 1957).

Notes:

Mean values are arithmetic means of all respondents based upon the following coding:

1 -- of utmost importance
2 -- of great importance
3 -- of considerable importance
4 -- of some importance
5 -- of little or no importance

Number of responses compiled: Governmental - 17,439, Industrial - 3,137.

expect if it were necessary or desirable to organize and control these creative groups. The desire for professional freedom and the chance or opportunity to formulate individual ideas and to follow up interesting leads is an important factor for any work which demands an imaginative approach.

PART IV

CONTROLS FOR CREATIVE RESEARCH

CHAPTER VII

THE APPROACH

The planning and control of a research program is dependent upon the manager's knowledge of the factors which contribute to the scientist's and engineer's job satisfaction. It is therefore essential to determine what scientists and engineers think are the facts surrounding their employment. What they think are the facts may be more important than the facts themselves. The management of scientific and engineering functions in industry and government requires an insight into the attitudes, values and thought processes of these professionals. The formulation of any systematic, rational organization must depend upon an understanding of these factors.

A possible approach to the management of a creative enterprise includes elements of both scientific management and human relations. This approach was designated by Ordway Tead as administration by objectives,[35] and was proposed as a means of broadening competence by Peter Drucker.[36] Such an approach or philosophy is a new policy of the International Business Machine Corporation. Basic research in this company originated in 1927, as a centralized corporate function concerned with advanced concepts as contrasted with product developments. The management control of this function is almost totally

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[35] Ordway Tead, The Art of Administration, (New York: McGraw-Hill Book Company, 1951).

[36] Peter Drucker, The Practice of Management, (New York: Harper & Brothers, 1954).

dependent upon an upper budgetary limitation on the total basic research expenditures. The budget allocation for this function is stated in the aggregate, and is dependent upon "how much the company can afford to expend".[37] Allocation by specific project is made within the basic research organization.

Administration by objectives depends upon two elements. First, the ability of management to make the objectives and policies of the enterprise clear to the individual employee is necessary. Secondly, the coincidence of the institutional goals of an individual's employment and his personal integrit his social and personal ambitions must occur. At this point, higher management is able to assign the individual an area of responsibility and allow him a good deal of latitude regarding the method of fulfilling that responsibility. The basic assumption of the administration by objectives approach is that if the goal of the project or program is jointly agreed upon the determination of the procedure should be left as far as possible to the recipient of the delegated authority. As the individual's ability develops, and at the same time as he is cooperatively engaged in further definition of larger, common objectives, the authority granted him should be increased.

Involvement and participation can be the source of motivation when to a considerable extent the officials and employees are their own bosses. Democratic planning of objectives and policies provides the individual latitude of method and opportunity for growth.

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[37] C.V. Boulton, Assistant Treasurer, International Business Machine Corporation, New York, "Financial Management of I.B.M.", Lecture given before the George Washington University Navy Financial Management Course, Washington, D.C., April 3, 1962.

One of the primary difficulties of increasing the area of delegation and cooperation is the necessary increasing emphasis on coordination. The insulation of administrators and managers from the day-to-day operations can be counteracted by frequent face-to-face relationships. The way to coordinate is through the human touch; through conferences, informal huddles, and judicious committee meetings. There is no substitute for the top executive getting a worm's-eye view for himself. It is only through personal association that he can give each member of the organization the sense of the whole and the sense of how the role of each is vital to the rest.

A proponent of the future possibility of systematic planning and scheduling of invention might support his point of view by noting the success of recent sophisticated and mechanized management systems. The Navy's PERT ("Program Evaluation and Review Technique") system is one of the most advanced and sophisticated systems of management yet applied to a research effort. It is a system for program time and cost management to be applied to complex decision-making problems. An operations research effort developed this management technique in 1958 to fulfill two general objectives.[38]

The objectives were to provide a systematic technique for communicating and monitoring responsibilities, and to define the nature of necessary overlapping responsibilities. Direct responsibilities for a task with its necessary scheduling were assigned to a single individual with deliniation of supporting responsibilities to other individuals. In order that this technique fulfill its key objectives, input data from the responsible

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[38] Willard Frazar, "Navy's PERT System", The Federal Accountant, Vol.XI, No. 2, December, 1961, pp.123 - 124.

individuals were necessary. Data were needed to assess the validity and reasonableness of the plans and schedules, to measure the progress at any time, and to predict the probability of meeting future scheduled sub-tasks.

The system recognizes that the field of research and development involves wide ranges of uncertainty about the time and nature of the possible outcome. In operation, PERT links the identifiable events in a time frame which portrays their interdependencies. The uncertainties involved in the estimates of time necessary to move from event to event must be determined in terms of probability. The system is then able to determine relative criticality of the different series or combinations of sequentially-related events.

The important limitation of a management system such as PERT is the accuracy of the input data. Distribution of time probability is generated by electronic computer. It is important to note that this distribution is a result of estimates of most likely time, optimistic time, and pessimistic time. These estimates must represent time for meeting the same technical performance specifications. In order that these estimates be most accurate the estimator must be the person most expert in the particular sub-task being considered. Quite obviously, this expert is ultimately the scientist actually working on the particular requirement. He is the person best equipped to forecast time to successful completion of an event. His estimate depends on a synthesis of the energies he visualizes must be expended on the sequential steps of his conceptual plan.

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[39] U.S. Special Projects Office, Bureau of Ordnance, Program Evaluation Research Task: Summary Report, Phase 1, Washington, D.C.: Department of the Navy, July, 1958.

This technique does provide a high speed system to keep track of an over-all technical effort. It is an effective management tool at high levels of management. It does not provide direct control over the effort in the usual sense of control. The budgeting, scheduling and technical direction of the event completion does not flow downward from high levels of management to the research worker. In operation the system provides systematic, central auditing and analyzing of the individual research worker's estimate of time, energy and funds which must be devoted to the successful completion of a particular sub-task or event.

Since this paper is primarily concerned with the management of creative effort at the level immediately above the research worker, the application of the PERT system becomes one of systematic review rather than technical, budgetary or planning control.

For administrators of scientific research an understanding of the technology is indispensable. The outlook of this type of person is different from that of the research scientist and different also from the industrial administrator. He is a complex blend of the two. The mental discipline, the cultural sophistication, the understanding of human relations, the ability to learn from experience, and the ability to synthesize are all mixtures of characteristics expected in each of the above groups.

The basic philosophy of good scientific administrators can be contrasted against the accepted management philosophy of industry of a half century ago. Industrial managers of this period viewed manpower as a commodity. They considered the economic investment in people on much the same basis as the economic investment in plant property or inventory. Corporate profit was the

primary and only goal. Paternalistic charity was the only humanistic input. The emphasis was based on authoritarian control which was derived from organizational title and position. The organization was structured in terms of fragments of fixed responsibilities pyramided through specific line authority. The basis of control was fear. The reaction was a non-creative, inflexible, conservative, defensive obedience to control.

The philosophy of a successful scientific administrator can be compared with the more liberal democratic point of view of some present-day industrial managers. This cooperative approach stresses the necessity of a management objective which includes the individual worker's well being. When the organization and the individual have a common purpose, good leadership can influence subordinates to work with management in pursuit of the goal. Permissive, multiple management, stressing democratic participation irrespective of title, position, authority or responsibility, ill enable people to develop to meet their objectives. Under this type of administrative philosophy, organization is structured as an informal group of individual personalities and skills working on a common endeavor.

This philosophical approach to management of scientific workers would appear to be the most effective way of getting creative things done through and with imaginative people.

CHAPTER VIII

THE MAN

There appears to be no standard list of necessary executive personal qualities; the successful manager may be weak in some traits often considered "essential", and the manifestation of qualities may vary greatly from time to time in the same individual. Others have identified effective administration in terms of the skills of the administrator. An administrator is assumed to be a person who directs the activities of other persons and is responsible for achieving certain objectives through these efforts. Within this definition, three basic skills appear vital to successful administration. The interrelation of technical, human, and conceptual skills are manifested in the performance of effective administration.[40]

Technical skill involves specialized knowledge and analytical ability within a specific discipline. In scientific research organizations the administrator's need for this skill would require formal education in the discipline or disciplines of the men being supervised.

Human skill involves a natural and continuous sensitivity to the attitudes, assumptions, and beliefs of and about other individuals. An open-mindedness toward the viewpoints and perceptions of others, and an ability skillfully to communicate against the backdrop of their beliefs, needs, and

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[40] Robert L. Katz "Skills of an Effective Administrator", Harvard Business Review, January - February 1955, Vol. 33, No. 1.

motivations are prime requisites of the skill of working with others. The application of superficial techniques will not be effective because, in time, the executive's true self will show through.

Conceptual skill involves the ability to see the problem or function as a whole. Recognition of the significant elements and their relationships and interactions in a particular situation is the basis of this skill. Coordinated direction toward an organization's goals depends heavily upon this ability.

The increasing cost of modern scientific equipment makes the multiple use of these expensive items essential. The requirements for systematic administration and scheduling result. A big organization invites waste of manpower in the field of scientific creativity. There therefore must be a fine sensitivity for maintaining balance between the expensive annual research program, and the careful nurturing of individual initiative and talent.

It is important first to differentiate between direct line supervision over scientific activity and indirect staff aids to research. The employment and handling of personnel, the keeping of the accounts, the purchase and maintenance of equipment, and other nonscientific functions are necessary and time consuming staff functions of any large-scale enterprise. Even these staff aid functions require some knowledge of the field of science being investigated. As an ideal therefore, the official in charge of one of these functions should have engineering or scientific training. In order best to utilize engineering and scientific ability and training it has been standard practice to employ specialists trained in the fields of their staff functions.

The legal, personnel, budget, public relations, patent counsel, purchase, and other staff aids are rarely scientists.[41]

The selection, training, and background of the line administrators is a more difficult and controversial problem. Should the administrator in direct charge of research activity be trained in science or in management? Successful examples can be cited from both backgrounds. David Lilienthal, trained in management and not in science, served as chairman of the Atomic Energy Commission in direct control over one of the largest, most important research and engineering programs. Vannevar Bush, a scientist, administered the Office of Scientific Research and Development which produced the atomic bomb.

The task of the administrator or research director is a dual one, including both technical and administrative aspects. The good research director must either be a scientist who has native or acquired administrative ability, or an administrator who has acquired a knowledge of science and of the ways of scientists. With either solution, the research director should supplement his own skill with that of persons trained in the other field. The technical responsibilities include some planning, execution, review, and liaison. The administrative responsibilities include budgeting, personnel matters, scheduling, progress reporting, and public relations to some extent. The most important responsibility is to provide leadership.[42] The leader

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[41] Lowell H. Hattery, "New Challenge in Administration", Scientific Research: Its Administration and Organization, ed. George P. Bush and Lowell H. Hattery (Washington, D.C.: The American University Press, 1950), pp.3 - 4.

[42] Hugh L. Dryden, "Responsibilities of Research Directors", Scientific Research: Its Administration and Organization, ed. George P. Bush and Lowell H. Hattery (Washington,D.C.: The American University Press, 1950), pp.37-46.

commands the respect of his associates and in turn respects their ability. He treats them as individuals, and not as bodies. Such is the ideal "direction" for research effort.

President Eisenhower defined leadership as "the art of getting somebody else to do something you want done because he wants to do it."[43]

Many European experts who came here after the war to inspect our research methods reported that our scientific intellect was inferior to theirs; our advantage was in the attitude of the individuals who did the creative research work.[44] Leadership really requires a more subtle and perceptive approach than the Golden Rule.[45] The leader must understand the goals and purposes of those who work for him. He should treat them as they would like to be treated; not as he would like to be treated.

Technical scientific skill is no longer a sufficient base for successful management of a research organization. A typically accepted theory of the 1920's is extracted from the Wickenden Report:[46]

> The engineer of tomorrow will not rise to leadership by abandoning his distinctive role or by permitting it to become ill-defined. He will do so by becoming a more competent engineer, by extending the reach of engineering methods and ideals to larger realms of life, and withal, by making himself a teammate eagerly desired by other types of men.

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[43] Perrin Stryker, "The Rarest Man in Business," Fortune, May 1959, Vol. LX, No.11, p.44.

[44] Eric Larrabee, "Our Face to the World," Horizon, Vol. 2, No. 5, May 1960, p.7.

[45] W.C.H. Prentice, "Understanding Leadership", Harvard Business Review, September - October 1961, Vol.39, No.5, p.145.

[46] Report of the Investigation of Engineering Education 1923 - 1929, University of Pittsburgh, Pittsburgh, Pa., 1930, Vol I, p.53.

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Recently, some of our largest corporations have deliberately taken scientists and engineers out of business for periods of six months or more.[47] The present feeling is that in order to add the humanism which their education had lacked, it is desirable to give them a liberal education. Their former education had evidentally been too narrowly specialized on skills which would equip them to gain a first technical appointment. Larger business enterprises have now realized that an executive cannot manage people successfully by delegating personnel management and human relations to staff assistants.[48] The only way effectively to deal with people is with a personal concern for them; this is derived from and integrated with the purpose of the tasks to be done.

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[47] Robert A. Goodwin and Charles A. Nelson, editors, Toward the Liberally Educated Executive, (Mentor Books, New York 1957), p.16.

[48] Ibid.

CHAPTER IX

THE RESPONSIBILITIES

To gain a better appreciation of the problems of first-line supervision in an organization whose product is creativity, it is helpful to contrast the necessary attributes of this type enterprise with those of a bureaucratic repetitive production enterprise. Creativity stresses change, repetitive production stresses order; one seeks the new, the other seeks prudence and discretion; one is adventurous, the other conservative; one creates the gains while the other attempts to consolidate gains; one relies on acumen, the other on logic; one stresses artistry, the other accountability. Creativity generally requires a flexible initiative arrangement of functions and personnel and usually stresses the quality of the individual. Repetitive production processes tend to guard the old, neat arrangement of functions and personnel and basically stress the quality of the group.[49]

In general there are two extreme types of supervisors. On one hand, there are the self-centered, domineering, and exploitative; on the other, there are those who are sensitive, dedicated, and helpful. It is contended that, of these extremes, only the second type can be lastingly successful. This kind of supervisor will recognize that many principles of management are merely common sense, and must be evaluated in terms of the people and tasks at hand. He will de-emphasize rules and formal direction on the ground that informal cooperation is more effective.

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[49] Marshall E. Dimock, Administrative Vitality, (New York: Harper & Brothers, 1959), pp.121 - 135.

In some kinds of endeavors, with some workers, decentralization and informality may lead to poor performance. Men who are left alone may be apt to settle down into routine, habitual responses; their minds may lose resiliency and drive, their outlook may become dull, and their responses slow. These situations require clear lines of organization, definite established practices and compartmentation of responsibilities. Any skilled group of creative research workers would, however, be stifled by such an organization. Nothing would more quickly destroy their cooperation than a rigid and uncompromising management attitude. A sensitive, creative being can best be directed with a feather light rein. Democratic and participative management on a personal level, having clear objectives and a clear philosophy of management, will prove most effective for creative research efforts.

Of the many possible managerial responsibilities which could be assigned to a scientific research effort, a list of the most probable follows:

1. Recommendations as to the most profitable lines of inquiry,
2. Estimates of the cost of each project,
3. Probability of success of each project,
4. Knowledge of what can be salvaged should the project be unsuccessful,
5. Ability to subdivide the project into the necessary tasks,
6. Routine progress reports to higher management,
7. Facilitation of interdepartment and intradepartment communications, and
8. Knowledge as to when to stop a project.[50]

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[50] Marshall E. Dimock, Administrative Vitality, (New York: Harper & Brothers, 1959) p.199.

Any unnecessary concentration of these responsibilities among a few executives will tend to limit initiative, create delays, increase expense, reduce efficiency and retard creative development. Decentralization of scientific research management is then the approach most probable of achieving success. To promote initiative and resourcefulness, together with patience and restraint as an expression of the dynamic individualism of all the research workers, is the ultimate goal. Freedom and initiative at the individual level is a prerequisite, since it is at this level that the real power of accomplishment rests.

The advantages of decentralization and the importance of the first-line supervision in scientific research work points up the need for a philosophy of management at this level. This philosophy must be based upon tradition, high morals, intellectual rationality, the character of the scientific worker, the need for innovative freedom, and the necessity for the various management functions. The prime factors are innovative freedom and the character of the individual being supervised. The individuals need help in coping with nontechnical problems, in overcoming problems in their work, in wisely choosing the problems to work on, and help in judging the value or significance of their work. The research worker is today rarely self-sufficient. He not only needs assistance in his technical and nontechnical work; he needs encouragement and assistance to insure that his work receives the recognition and utilization which it deserves.

For successful research, it is absolutely essential that a man work on a problem that he believes to be good for him and that he approach the problem in a way in which he has confidence. He need not necessarily invent

the problem or the general approach toward its solution. When a man feels it is a bad problem, either because the problem is no good or because it is beneath or beyond his capabilities, the course of productive research cannot be followed by him.

Scientific research necessarily is nonstandard and individualistic. A top-quality scientist cannot be treated as a mere employee, for he is creative. He does not think along "conventional" lines, he does not readily accept direction from others. The very circumstances which make it difficult to administer effective control of scientific research may also intensify the need for such control. The control need not necessarily dominate, subject, or overpower; it is intended only to insure that an organization is working effectively toward its objectives.

In executing a basic research function, two dichotomous and conjugate principles are involved: (1) management must be able to direct and control, and (2) research workers must have freedom. Management must be willing to accept broader deviations from conventional behavior in order that an individual's creative ability can be judged solely on his actual contributions. To obtain a measure of profitable control, management must stimulate creativity and pay attention to the evaluation of an individual's technical ability. This technical evaluation can best be made at the first-line supervisor's level since very few managers can maintain a technical competence necessary for judging the work of more than six to nine capable research workers.[51]

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[51] Clinton J. Chamberlain, "Coming Era in Engineering Management", Harvard Business Review, September - October, 1961., Vol. 39, No.5, pp.91 - 92.

Planning and evaluation, even down at the first-line supervisor's level, is a most difficult task. How can anyone plan and judge another's thinking; or for that matter, even his own. The possible variations and complexities of mental synthesis and analysis require a high degree of flexibility and an increased technical knowledge on the part of the planner. Historical experience provides only dubious assistance. The rapid advances in science and technology, the ever changing skill-level requirements of the solution of a problem in process, the unpredictability of a "break-through", and the improbability of successful solution all add to the tenativeness of any plan.

Some degree of planning can nonetheless be accomplished, even on basic research projects. Scientific doctoral work involves basic research. The doctoral candidate must plan his project so that the laboratory investigation can be completed within a specified period of time. In proceeding from the basic research end of the spectrum toward the applied research and product development end, it becomes increasingly possible to predict the results which can be achieved and the time and energy required to achieve them. Though it is sometimes possible to predict the time necessary to achieve an answer it is rarely possible to determine whether or not the answer will be useable or optimum. Predictions can usually be made about the probable success of the whole research effort with much greater assurance than can predictions be made about individual projects. Mr. Crawford Greenewalt, president of duPont, a highly successful research organization, is credited with the statement that, "although 95% of the research projects undertaken by the company are unsuccessful, only 80% of the research dollars are expended on these unsuccessful projects".[52]

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[52] Lawrence P. Lessing, "How to Win at Research," Fortune, Vol. LII, No.4 (October, 1950), pp.117-118.

Direct and centralized planning and control of research efforts may be neither necessary nor desirable. Of the three development programs of jet aircraft engines, the greatest degree of central control was exercised in the United States, the next greatest in Great Britain, and the least in Germany. All three programs started at approximately the same time. Success was achieved in inverse order to the degree of control exercised. Germany developed a successful engine first, then Britain, and finally the United States.[53]

This is not to say that the research worker wants to be without supervision. He does want and need a considerable amount of freedom -- freedom from strict supervision, freedom to plan the details of his work, freedom to discuss his work, freedom to publish technical papers and attend technical symposia, and especially freedom to spend part of his time working on ideas which are completely his own and unrelated to his assigned work. By training and inclination, the basic researcher wants to know why things work. This spirit of logical inquiry extends to all the rules, practices, and decisions which affect him. He may tolerate illogical control practices but he will not cooperate to make these practices effective until he is personally convinced of their value. Conversely, he is usually willing to accept practices whose logic can be demonstrated.

Despite the research worker's respect for logic, or perhaps because of it, many of them overestimate the importance of reason and underestimate the importance of emotion in human situations. Thus, an excellent research worker

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[53] Robert Schlaifer, The Development of Aircraft Engines, (Boston: Harvard Business School Division of Research, 1950), Chapter XIII.

must be a very poor administrator. A recent survey of some one hundred scientists turned industrialists who have amassed a worth of more than a million dollars revealed some interesting aspects with regard to their motivations. This survey indicated that these scientists turned industrialists do not ordinarily start their company with any close calculations about capital gains. Most of them are simply prejudiced against working for, or even with, someone else. They still retain the values and preoccupations of the scientific, rather than the business community. Some of them are only foggily aware of the fact that they are millionaires. These men are characterized as earnest, idealistic and ingenuous. The strong desire to be independent was the primary reason for their venture into the industrial field. They tend to view their businesses as competitive games. It is the competition that makes their work interesting, and the money is just a way of keeping score.[54]

The typical research worker does not understand or care much about the problems which confront the management but do not directly affect him. He usually prefers to work by himself as much as is consistent with the laboratory program and its goals. He views his own specific technical problems as of paramount importance. The creative researcher in the mechanical science field is typically not interested in the mechanics of his car. He is not interested in engines that exist, but rather, he is concerned with engines that as yet we don't know how to build.

The problems and conditions surrounding research change so frequently that any control techniques applied must be flexible. This fact, that changes take place with considerable rapidity, also implies that excellent channels of

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[54] "The Egghead Millionaires", Fortune, September 1960, Vol. LXII, No. 3, pp.172 - 178.

communications must exist in order that the knowledge of these changes can be quickly transferred to the persons affected by them. Accidental happenings, such as the discovery of penicillin by Dr. Fleming, necessitate controls flexible enough to allow plans to be quickly changed to accommodate the chance discovery or the unforeseen delay. Controls also should aid, or at least not prevent, the creation of an environment in which research workers will be encouraged to observe, appraise, and capitalize on the significance of an unplanned development.

Because of the inherent instability of a creative research project the attendant organization must also be flexible. The once successful egg-crate organization of research does not work well today.[55] Nearly every project requires the services of theoretical and applied scientists from several different fields. The solution of today's research problems often requires delving into foreign disciplines; not only across a broad applied front, but also deeply into the very roots of a companion science. Frequent organizational changes are brought about not only by this requirement, but also by shifts in area of most urgent difficulty, interorganization communications difficulties, recent technological advances, etc.. Though modern research organizations must be capable of frequent organizational changes, care is necessary to provide the research worker with the stability and security he needs. The successful solution of this dilemma is primarily dependent on capable leadership -- usually personal and informal.[56]

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[55] "Vexing Environment for Technical Management", Industrial Research, Vol. 4, No.1 (January, 1962), p.22.

[56] Clinton J. Chamberlain, "Coming War in Engineering Management," Harvard Business Review, September - October 1961, Vol.39, No.5, p.92.

The scientist or engineer of the early decades of this century was in a most advantageous position to provide this leadership and rise to managerial positions. He was, other than a few lawyers and accountants, virtually the only person who had the advantage of intellectual development based on a systematic higher education.[57]

Because he was available, had knowledge of the business world by acquaintance, and understood production techniques, he tended to qualify for the executive positions. The development of scientific management tended to reinforce this trend through the insistance that an intelligent approach to management problems must be based on a scientific education. Recent emphasis on human relations in management ability has pointed out an apparent deficiency of the typical researcher in a magerial position.

Perrin Stryker identifies executive leadership by the following attributes:[58] (1) the innate propensity for change and innovation and (2) the ability to change men's beliefs, attitudes and behaviors.

"The general functions of management begins whenever the work to be accomplished is too much for one man".[59] When the man requires an assistant he must then delegate some of work to be accomplished. The key to delegation is

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[57] L.F. Urwick, "The Engineer's Debt to Management," Mechanical Engineering, March 1961, Vol. 83, No. 3, p.34.

[58] Perrin Stryker, "The Rarest Man in Business", Fortune, May 1959, Vol. LX, No. 11, p.42.

[59] Edward C. Schleh, Management by Results, (New York: McGraw-Hill Book Company, Inc., 1961), p.7.

to "delegate by the results that you expect of the man".[60] Whenever a man has responsibility for a result, he should also have the responsibility and authority for planning its accomplishment. In the event the man is unable to make a necessary decision, he should have the responsibility for making an analysis of the problem and presenting his recommendations to the decision-maker.

In considering the management functions of a research organization, the most important aspect is the planning decision. This is an investment decision; and, as is true with all investment, the problem is one of deciding how best to expend financial resources now so as to maximize the future return. Because the data upon which this decision is based is necessarily vague and incomplete, no one can rationally prove that the decision actually made was the best one. This decision must certainly be based, in large part, on management's judgment of the competence of the men whose time and energy constitutes the investment.[61] It is in this investment concept that the most important aspect of financial control both begins and ends. Financial control -- the control of the expenses of doing business -- can be better understood and less restricting to scientific researchers by wider and lower distribution of financial authority and responsibility. This distribution must, of course, be limited by the aggregate investment decision.

Technical control is far more subtle than financial control. Technical control is concerned with the direction of the creative effort expended so as to maximize output. It therefore implies cognizance and manipulation of the

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[60] Edward C. Schleh, Management by Results, (New York: McGraw-Hill Book Company, Inc., 1961), p.8.

[61] Robert N. Anthony, Management Controls in Industrial Research Organizations, (Boston: Division of Research, Harvard Business School, 1952), p.333.

technical output of research workers. Since this output is primarily the creative product of a human brain, technical control is really the control of the mental capabilities of human beings.[62]

Since the aim of research is new understanding or new accomplishment, the course toward this goal must be creative, intelligent, and enthusiastic work.[63] Research scientists must have a sufficient measure of freedom at hand when they require it. Clearly, this freedom is vitally important to research, but other somewhat inconsistent things are important also. Management functions obviously affect the researcher's freedom. Delegated responsibilities keep him from following up every idea or inclination he has. The capital value of necessary apparatus ties him do n. Specialization on one problem area lessens his ability to tackle an idea in another area. Good research workers, however, suffer often more from a lack of help than from a lack of freedom.[64]

The creative ability may in certain instances be enhanced by teamwork of a group. It is possible for the team or group to solve problems and make decisions where no individual member would be successful. This phenomenon is possible through one or more of the following manners: (1) by reinforcement between individuals of the same discipline, (2) by differences between individuals in diverse disciplines, or (3) by combination of the contributions of the less-skilled to the greater-skilled.[65] Whenever such a team or group

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[62] Clinton J. Chamberlain, "Coming Era in Engineering Management", Harvard Business Review, September - October, 1961, Vol.39, No.5, p.91

[63] J.R. Pierce, "Freedom in Research", Science, September 4, 1959, Vol. 130, No. 3375, p.540.

[64] Ibid., p.541.

[65] Henry E. Metcalf and L. Urwick, Dynamic Administration: The Collected Papers of Mary Parker Follett, (New York: Harper & Brothers, n.d.), p.299.

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organization is used in research, the person who heads up a team must be an effective and qualified leader. As disciplines have fragmented due to ever increasing specialization and as problems have increased in complexity, the need for coordinated cross-disciplinary approach increased.[66] Like other forms of teamwork this group approach is neither spontaneous or automatic. Capable leadership is the foundation for its success.

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[66] George P. Bush, Teamwork in Research, (Washington, D.C.: The American University Press, 1953), pp.181 - 184.

CHAPTER X

CONCLUSIONS

The way a research program is managed can vastly influence its relative contribution. This contribution can be effected not only by the skill and efficiency of the research workers in the laboratory, but also by the integration of the program into the total organization's goals or objectives. Management's functions include support for planning, organizing, motivating, coordinating, and controlling aspects of research. How best can these management functions be executed so that their influences will result in a maximum research contribution?

Many detailed lists of the research manager's responsibilities have been compiled.[67] The five general activities noted below appear to include the research management responsibilities which most critically influence research integration. These activities include:

(1) knowledge of the technical needs of the total organization and selection of areas where the scientific effort should be applied;

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[67] The following sources provide such listings:

G.W. Howard, Common Sense in Research and Development Management, (New York: Vantage Press, 1955), pp.9 - 10.

W.E. Rockwell, Jr., "Top Management's Role in Industrial Research," Management Review, Vol. XLVIII, September, 1953, p.498.

Ralph D. Bennett, "Research Management," Mechanical Engineering, Vol. LXXII, July, 1950, p.539.

(2) selection, training and retention of skilled scientific talent to work in these areas;

(3) review and appraise the research progress, and lead the research effort along a channel most useful from the total organization's point of view;

(4) influence the total organization to provide the proper support for the research program; and

(5) provide a conducive environment for creative work.

The first responsibility is predominately one of planning. A balanced plan, which attempts to integrate the technological needs and the skill and economic capacities, is the objective. This research plan should select areas of inquiry, but it should not overplan to the extent that the details of the scientific attack are specified. Overplanning can be extremely damaging because it tends to stifle creativity and originality. Finally, the plan must be flexible and periodically re-evaluated. To gain acceptance of such a plan, maximum participation by the research worker is important. Additionally, in order that the plan be objective, the creative worker should review it and contribute the applicable information only he can provide. The technical planning, both to determine the technical feasibility and the necessary research action, should be left to the research workers. Fundamental research is best performed with the greatest degree of freedom from organizational control. The plan should contain no more detail than management expects to directly control. Priorities and financial or economic limitations can serve as sufficient guides for technical planning.

In reviewing the plan by evaluating the research output, management must not follow a negative or loss technique. It would be possible to accumulate the costs of all projects which had been abandoned short of a useful conclusion. This approach would be more detrimental than helpful to good research planning. It would tend to influence selection of safe projects rather than risky ones which might offer a much greater return. It might influence continuation of projects which should be terminated in the hope that continuation might yield some tangible results. It would, further, ignore the value of the well conceived, well executed, but unsuccessful project. Since about nine out of ten research projects never reach fruitation, figures derived from such an approach could have negligible value.

The second responsibility listed above is primarily one of organization. The ability and skill of the research worker is an essential determinant of research success. Adequate administrative and technical assistance must be provided in order that the skilled innovator's energy can be conserved and he can be made master of his time. The assistance provided includes secretarial help, organized library facilities, laboratory assistants, test equipment, routine personnel administration, problem suggestion, etc. The research director can provide the important link between research personnel and the remainder of the organization. He acts as liaison in interpreting the views of top management to the research staff; and the needs, progress and results of research to top management. He serves to coordinate research activities. He also is in direct and authoritative control of the administrative and technical assistance functions within his purview.

The third responsibility listed is primarily one of control. Before control can be exercised, management must be able to evaluate the progress being made by the research effort in terms of the intended objectives. This evaluation is the basis for any control. Management can do no more than redirect or control in such a way as to improve the probability of ultimate success of the function it guides. Progress evaluation and subsequent control should be approached in an extended time frame. The productivity of research is cumulative and can not be assessed on a monthly basis.

A warning against overcontrolling again seems in order. No amount of managing can develop a creative scientist. It may be privileged to provide encouragement, recognition, working facilities, and information in order that this gifted individual is able to make the greatest advances in human knowledge. The warning has been well expressed by a leading scientist of the past half century.

> One is immediately confronted by the difficulty that science in its highest expression is essentially individualistic and democratic. It resents autocratic control, languishes and becomes sterile under minute oversight and direction from outside.[68]

The fourth responsibility listed above is primarily one of support and has been discussed under the organizational responsibility heading.

The final responsibility is one of motivation and is of extreme importance in the management of creative research. The atmosphere or environment which will be most conducive to successful research work is one

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[68] Arthur D. Little, "Organization of Industrial Research," Topical Discussion in Industrial Research, Proceedings of the ASTM, Philadelphia, Pa., Vol. XVIII, Part II, 1918, p.19.

best adapted to the personal goals and values of the individual researcher. The objective is to heighten the interest, diligence, brilliance and productivity of scientific personnel through variation of the factors which are most likely to influence their attitudes toward their work.

The constructive simulation of such an atmosphere depends upon many factors. Competitive starting salaries are necessary to attract young scientists with creative potential. Sizable increments can serve to provide recognition of scientific skill and accomplishments. Expanding the technical pay structure can also serve to reduce the pressure to seek adequate rewards in administrative fields. The scientist's skill and creativity can generally be more productively utilized in the scientific rather than the administrative field. Monetary rewards do not, however, comprise the most important motivation.

Research leadership which stimulates creativity without being domineering is more vital. The problem facing the research executive is to lead and control without seeming to lead or control. Since productivity in research organizations is essentially dependent on individual creativity, leadership is dependent on individual, informal, personal association. The good leader can provide the stimulation, encouragement and opportunity necessary for the researcher's efficient attack on the existant boundaries of knowledge.

Proper facilities also enhance creative motivation. Some concerns have gone so far as to attempt duplication of the university atmosphere in landscaped suburban palaces. This emphasis may be excessive, but some

balance should be sought between the required facilities and those desired by the research workers.

A relaxed atmosphere is also needed. The creative process is stimulated by allowing time for contemplation and idea exchange. The laboratory environment should free the scientist, to the maximum extent possible, from the pressures of personality conflicts, time deadlines, routine hours, repetitive jobs, etc. Research organizations should be less severely organized and regimented than routine or repetitive processes. Freedom and democratic participation should be emphasized. The leisure and freedom of this relaxed atmosphere is important, but the research worker must not be allowed to lose sight of the competitive need for scientific accomplishment. The sense of urgency can be stimulated by good administrators, but inflexible or unreasonable demands should never be laid down.

Recognition and acceptance of new scientific ideas is another important motivation. Management should encourage dissemination and exploitation of the researcher's successes. Individual researchers should have the opportunity of being recognized by others in the field.

Creativity in one field may be stimulated by exposure to or contact with the creative work of others in a different field. Proper opportunities for broad professional interchange of ideas and problems should be provided. Freedom to attend scientific meetings, conferences, seminars and symposia should be given wherever possible. Compartmented research organizations are to be avoided. The informal atmosphere which does not stress organization structure nor provide the usual depth or rigidity is more appropriate to stimulate creativity.

The management of a creative effort is limited primarily to administrative guidance and assistance; and review of the estimated and actual time, effort and money expended.

In the first category, the management function includes the selection, education, training and assignment of assistants; provision of special equipment and facilities; creation of an environment for democratic and participative relations between work groups; and promotion of a high correlation of organizational and personal objectives. These functions are necessary in order that the critical resource, creative manpower, can be most efficiently utilized. Clerical and other noncreative, nonintuitive tasks should also be provided in order that the undisturbed productive research time can be maximized.

In the second category of management functions, review of estimated and actual research accomplishments, the manager must rely upon the research worker as a prime source for estimates. The manager must recognize the low degree of direct time coupling possible in forecasting future research successes. He must also recognize the tentativeness of any planned approach and retain sufficient flexibility to accommodate both unforeseen delays and chance discoveries. The necessity for flexibility in both plan and organization is inherent in research management. The very nature of the work is nonstandard and individualistic.

In general, management's primary responsibilities are those of assisting and encouraging the research workers. Direct personal associations in pursuit of these responsibilities will best promote acceptance of the organizational responsibilities and goals. When the workers' personal goals

coincide with those of the organization, technical authority can be delegated within the existing limitations of elapsed time or dollar expenditures. This approach will enhance the creative productivity because of the professional freedom which will result. An environment which will encourage the expression of dynamic individualism can thereby be created.

The successful manager, like the successful leader, is the man who can direct a group toward an objective without any authoritative demands. A manager need only attempt direct control where he has failed as a leader. Direct control is neither needed nor desirable where there is a sensitive response.

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